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Solution to enhance the acceptability of solar-powered LED lighting technology

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ABSTRACT

Unavailability of grid based electricity is a major challenge facing a majority of developing countries, particularly the population in rural areas. Consequently, people are forced to use the kerosene lantern in much of the world for lighting. However, fuel-based lighting is contributing to global warming and causing serious health related problems. To address these issues, several developing countries are now encouraging the use of sustainable clean lighting systems – solar-powered light emitting diode system. In the present paper, barriers and mechanisms to boost the use of solar-powered lighting are discussed.

Contents

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1. Introduction

Rural economic development is a national priority in many developing countries. However, rural areas frequently lack the safe and uninterrupted electricity supply that is needed for the development of numerous economic activities. At the same time, the remoteness, isolation, and low electricity demand of many rural communities make them very unlikely to be reached by the extension of the power grid.

Therefore, off-grid generation systems seem to be the most suited to provide electricity services to these isolated rural communities. However, numerous barriers which are inhibiting the widespread adoption of solar-powered lighting systems need to be addressed. In the present paper, mechanisms to enhance the acceptability of solar-powered light emitting diodes (LEDs) lighting to rural population have been discussed.

2. Kerosene fuel lighting

About 1.6 billion people around the world live without access to regular electricity [1]. Many people in Asia and Africa without electricity currently use kerosene lanterns as a light source. Kerosene is an inefficient source of lighting and provides very dim and inefficient light. The light is only 2–4 lumens compared to a 60 W bulb with 900 lumens. The light is so poor that children can only see their books if they are almost directly over the flame. They inhale even more of the toxic smoke. Besides being unhealthy, trying to do school work with a kerosene lamp creates a barrier to education and learning.

2.1. Kerosene health risks

The World Bank (WB) estimates that 780 million women and children breathing particulate laden kerosene fumes inhale. Fuel-based lighting is inefficient, expensive, dangerous and unhealthy. Due to poor ventilation, fuel-based lighting poses serious health hazards that are serious and debilitating, such as respiratory and eye problems, particularly in developing nations.

Burning kerosene lamps indoors produces the following pollutants:

- Carbon dioxide (CO_2) causes global warming.
- Carbon monoxide (CO) replaces the oxygen indoors and can be fatal.
- Nitrogen oxides and sulfur oxides (NO_x, SO_x) cause lung and eye infections, respiratory problems and cancer. They are also contributors to acid rain and ozone depletion.
- Volatile organic compounds (VOCs) cause eye, nose and throat infections, kidney and liver afflictions, and are carcinogenic substances that are released into the atmosphere.

2.2. Kerosene fire danger

Many families cannot afford a proper bottle and wick and rely on a fragile glass bottle and a piece of rope for a wick. Fuel-based lighting has more probability of causing fires.

2.3. Greenhouse gas emissions

It is estimated that in 2005 about 77 billion liters of kerosene (paraffin) and gasoline/diesel per year was used by fuel-based lighting.

$$\begin{aligned}\text{Emission baseline } (CO_2/\text{year}) &= \text{kerosene baseline (i.e. kerosene consumption (l/year)} \times \text{emission coefficient efficiency}\\ &\quad \text{of kerosene } (\text{kg}\,CO_2/\text{l}))\\ &= (77{,}000 \text{ million l/year}) \times (2.63\,\text{kg}\,CO_2/\text{l})\\ &= 202{,}510 \text{ million kg}\,CO_2/\text{year}\\ \text{or} \quad &= 202.5 \text{ million metric tons}\,CO_2/\text{year}\end{aligned}$$

Currently, fuel-based lighting in the developing world is a source of 244 million tons of carbon dioxide emissions to the atmosphere each year, or 58% of the CO_2 emissions from residential electric lighting. *Also, subsidized kerosene for domestic lighting sometimes finds its way into vehicles with additional environmental consequences.*

Rising CO_2 and other green house gas concentrations in the atmosphere, resulting largely from fossil-energy combustion, are contributing to the global warming and to changes in climate [2]. Climate-destabilizing carbon dioxide emissions would continue to rise, attracting attention for the long-term sustainability of the global energy system. In 2030, energy-related CO_2 emissions would be 52 per cent higher than today and need to change these outcomes in order to get the planet onto a sustainable energy path.

To address the greenhouse gases (GHGs) emission problem, judicious and intelligent use of energy resources are recommended. The best option is to use the *more efficient and energy saving devices and appliances.*

New types of light sources and technology are desired to convert energy directly into visible light at room temperature without any emission of green house gases. In this context, solar-powered compact fluorescent (CFL) and white LEDs *provide* the solution with *less power consumption* and *almost no environment contamination*. The single greatest way to reduce the greenhouse gases associated with the lighting energy use is to replace kerosene lamps with solar-powered CFL and white LED lighting systems in developing countries.

3. Solar-powered lighting

3.1. Solar-powered compact fluorescent lamp (CFL) lighting

Solar-powered lighting systems are acquiring the center stage in rural lighting owing to cost-competitiveness and clean lighting without any GHGs emission compared to fossil fuel-based lighting. For the past few years, alternative to fuel-based lighting has been the relatively efficient compact fluorescent lamps (CFL) powered by solar photovoltaic panels (Fig. 1(a) and (b)). The essential components of solar home system are:

(i) Solar panel array to convert sunlight (photons) into electrical power.
(ii) Charge controller to charge a battery (increase its voltage).
(iii) Solar batteries for power storage (for off-grid systems).
(iv) High-quality cables for connection panels, and battery junction box.
(v) Sine wave inverter to convert battery DC output to AC (10–15 V DC input, 220 V AC output, 50 Hz) suitable to be connected to standard household appliances (optional).

Fig. 2 shows the CFLs powered by solar photovoltaic panels for rural lighting.

Features of CFL

- Preheating, high electronic efficiency. Polarity protection.
- Saves up to 80% of energy compared to an incandescent bulb.
- Rated voltage: 12 V (10.5–15 V) or 24 V (18–28 V).
- Rated wattage: 3, 5, 7, 9, 11 and 13 W (+5%/−10%).
- Color temperature: 2700, 4200, 6400 K, red, green, blue.

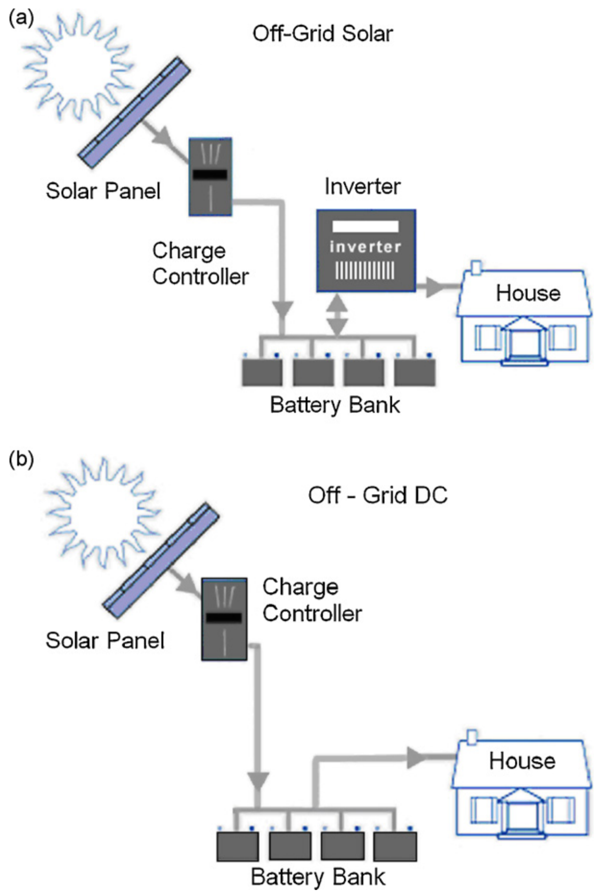

Fig. 1. (a) Off-grid AC solar power systems to provide power for normal AC appliances. (b) Off-grid DC solar power systems to provide power for only DC appliances.

- Operation temperature: −10 to 50 °C.
- Low temperature and low voltage start.
- Average lumens 150–715 lumens.
- Compact and robust product design.
- Life time: 6000 h.

Unfortunately, all fluorescent lamps including compact fluorescent lamp (CFL) contain small amount of elemental mercury (5–50 mg). Mercury is toxic by ingestion, inhalation and skin absorption with acute and chronic exposure effects, including central nervous system and kidney damage. Fluorescent lamps often contain over three times the concentration of mercury

Fig. 2. 12 V DC fluorescent CFL light bulb designed for photovoltaic PV system use.

allowable for landfill disposal. Through improper disposal methods, mercury may travel from the soil to various water sources. Lakes have been found to be polluted with mercury, rendering fishes unsafe to eat. As mercury moves up the food chain, it becomes more concentrated and poisonous to the human nervous system.

The United Nations Environmental Program (UNEP) noted that the mercury is a globally dispersed pollutant that is accumulating, and has called to minimize the further release of mercury.

Disposal of spent CFL lamps

Disposal of burned fluorescent lamps is a major concerned and needs to be addressed. European Commission Regulation – August 2005, Waste Electronics and Electrical Equipment Directive bans mercury containing lighting from landfill. In 2006, the EU set a target recovery rate of 80% of the mercury used.

In USA, regulations of mercury containing lumaires vary considerably between states. Some states have banned incineration of lamps, and others have banned lamps from landfill. In California, all fluorescent lamps must be recycled. Some states have established a collection scheme whereby householders can deposit spent lamps at some retail stores.

Some Asian countries have lamp endorsement labels that impose maximum mercury content. Japan, Taiwan and South Korea have implemented take-back programs. Australia has the recycling program of all spent lamps. Many developing countries have no regulation for disposal of burned CFL and fluorescent lamps.

Regardless of these regulations, how many people in developed and developing countries understand that they must be recycled. How many people just toss them in the trash like an incandescent? How many of the CFL are actually being recycled?

3.2. Solar-powered LED lighting

LED lighting technologies use light emitting diodes. A diode is the simplest semiconductor device. Broadly speaking, a semiconductor is a material with a varying ability to conduct electrical current. As a current passes through the LED, the materials that make up the junction react, and white light is emitted.

LEDs are considered to be future low power consumption lighting sources to urban on-grid population as well solar-powered LEDs clean lighting to rural off-grid communities [3]. *Furthermore, no GHGs emissions and mercury content are the most imperative features of solar-powered LEDs lighting* [4].With the adoption of solar-powered LED Lighting minimizes the use of kerosene fuel-based lighting. Replacing kerosene with the LED lights offers several benefits: reduced air pollution, improved studying conditions for children, saved lives from kerosene risk, reduced spending by poor families on kerosene, reduce health risks [5,6].The LED bulbs offer significant advantages over the traditional kerosene: emitting a brighter light, requiring less maintenance, improved studying conditions for children, saved lives from kerosene risk, and lasting longer. One of the greatest benefits, however, would be the elimination of fumes and smoke which would both improve the health of families and reduce greenhouse gas emissions.

4. Economics of LED lighting

In remote areas, the high cost of kerosene can consume much of a family's income. One lamp consumes 0.04–0.06 l/h, and the daily usage is of 3–4 h burn time. 1 l of kerosene per week times $1.00 USD = $52.00 USD per year (Table 1). The amount of light from the lamp is only about 0.2% of what the people in industrialized countries have for the same price.

Table 1
Economics of various lighting technologies in off-grid applications.

	Lamp type			
	Kerosene	Incandescent	Compact fluorescent	White LED
Efficiency (lumens/W)	0.018	5–18	30–79	25–50
Rated life (h)	Supply of kerosene	1000	6500–15,000	50,000
Durability	Fragile and dangerous	Very fragile	Very fragile	Durable
Power consumption	0.04–0.06 l/h	5 W	4 W	1 W
Color rendering index (CRI)	~80	98	62	82
$ after 50,000 h use	1251	175	75	20

Moreover, these lamps use kerosene, which has to be imported and is expensive or unavailable in rural areas.

Kerosene is far more expensive than electric lighting. The cost of useful light energy ($/lumen hour of light) for kerosene is 325 times higher than the inefficient incandescent bulb, is 1625 times higher than compact fluorescent light bulbs [7].

LEDs have already been commercialized and LED products are available in the market for end use although they do not have cost-competitive advantage with regard to other light sources as shown in Fig. 3.

Important features of LEDs for solar-powered lighting system

- Power consumption: 3–10 W.
- Luminous flux: 780 lux.
- Operating voltage LED: 12 or 24 V DC.
- Operating temperature: −30 to +60 °C.
- LED life time: 80,000 h.
- Power factor: 0.911.

5. Case study for solar-LED lighting in Tibet

Despite high rates of electrification in China, 25–30 million people remain without access to electricity. Fuel-based lighting is shown to be significantly more costly than solar-powered CFLs and solar-powered LEDs alternatives. Thus, there is a need to explore off-grid technologies for lighting in China. In this case study, they examined the lighting pattern in off-grid population in rural regions of the province of Tibet (Table 2).

5.1. Findings of the project

(a) The success of solar-powered CFL is dominated by the solar panel and battery components and scale with the power output needed.
(b) The retail costs of these systems to the end user are often prohibitive. As a result, the potential for these systems has remained highly dependent on subsidy.
(c) The local market for solar home systems in Tibet is largely driven by subsidies from the central government.
(d) A consumer market for solar home systems exists in the city of Lhasa, but its sales volume did not appear comparable to the subsidized market.
(e) Limitations associated with the current system: (i) there is no strong driver for innovation, (ii) the end users of the products have little influence on the product design and improvement, (iii) the products are provided free, or at low cost, there may be little incentive for the end users to invest in maintenance of the product.

Fig. 3. LED lamp sources for lighting.

Table 2
Case study – solar based LED lighting for semi-nomadic populations of rural Tibet.

Current lighting systems	Solar home system or diesel fuel lamps
Solar home Systems (CFL)	(i) Donated or subsidized by the central or local governments or outside organizations (like USDOE, WB, etc.). (ii) Villagers pay fee between no fee and $150 for their systems, depending on the amount of subsidy. (iii) Solar Panel – 10 or 20 W solar panel to operate 2 CFL bulbs. Sometimes radio, tape player, or television. CFL costs: $2–3, replacement time varied from 2 months to 2 years.
Diesel lamps	(ii) Small jars of fuel with a thick wick inside. As a supplemental source to solar-powered lighting. (iii) Fuel 100 ml gives light for 3 h per day. 1–5 l for 1 month. US$6–30 per year. (iv) Light output – very low.

(f) A significant percentage of the solar home systems encountered during the study were non-operational, either due to minor maintenance issues that could not be replaced by local villagers or due to defective products that could not be returned.

5.2. Reactions to solar-powered-LED lighting systems

Solar-powered-LED lighting is shown to be cost-competitive compared to fuel-based and solar-powered CFL lightings. Other benefits of LEDs are (i) ruggedness, (ii) significantly longer service life compared to competing electric light sources. Despite the potential benefits of LEDs, market forces are likely to spur innovation in solar-LED lighting options for the off-grid populations of Tibet. Villagers were asked to compare solar-powered LED lighting with traditional CFL bulbs and diesel lamps.

(i) The strong directionality of LED light was a major complaint.
(ii) Villagers welcomed greater luminance LED lightings.
(iii) Villagers did place a high value on daily operating time, and power consumption.

6. Barrier to consumer acceptability of solar-powered lighting

UNEP and several agencies of different governments are aggressively encouraging the use solar lighting system in their countries particularly in rural communities to reduce the GHG emission and global warming. However, a plethora of factors are inhibiting the rapid development of solar home systems. It is, therefore, necessary to identify barriers to penetration of solar lighting system and address concerns of consumers to boost solar lighting market.

6.1. Case study of Tanzania – barriers to solar PV technology transfer in Mwanza, Tanzania

Barriers to adoption and use of solar based lighting in Mwanza, Tanzania are displayed in Table 3 [8].

6.2. Solar home system in Botswana – a case study

In Botswana, more than 70% of the country's population lives in rural areas. They depend mainly on traditional agriculture and pastoration for their livelihood. Lack of access to on-grid electricity forced them to use fuel-based lighting system.

To address the issue of energy poverty among rural communities, Botswana Government initiated several program for rural electrification [9]:

(i) Promotion of solar energy by the Botswana Government.
(ii) Integration of grid and non-grid technologies.
(iii) Identification of an appropriate institutional framework for rural electricity using renewable energy.
(iv) Development of strategies for removing the barriers to widespread use of renewable energies.
(v) Promotion of women and children's welfare through the provision of photovoltaic power generation.

The government installed pilot project on photovoltaic solar system in three villages. In this model, service company provides electricity to households in a community for a monthly fee. A regular monitoring of revenue collected from participants is needed.

Some major impediments causing low use of solar home systems by rural communities are:

(a) Low-income status of most rural inhabitants which is a major factor/impediment.
(b) Fee for service model is an unsuitable model used by the authority – major factor.
(c) Migration of house owners from village status to lands, or cattle posts – secondary factor.

6.3. Case study of Morocco

The project is about to provide 101,500 rural households in all regions of Morocco with photovoltaic kits (75.7 WP (watt peak))

Table 3
Barriers to adoption of solar PV technology in Mwanza, Tanzania.

Barrier	Degree of importance	Methodology to redress issues
(1) Limited awareness of, and experience with PV technology and 12 V DC appliances. Energy is a low priority area among users.	Major barrier	Increase understanding of solar PV technology to the large community via TV/radio programs, personal networks.
(2) Inadequate business knowledge and capacity for distribution.	Major barrier	Build business knowledge and capacity for distribution of solar PV systems.
(3) Limited technical knowledge of proper sizing, installation, operation and maintenance.	Major barrier	Training, promotion, trade fair.
(4) High cost of solar systems, initial capital investment and operation and maintenance.	Major barrier	Link installation of PV systems with poverty alleviation projects.
(5) Low purchasing power of the rural people.	Major barrier	Subsidize promotion of solar technology.
(6) Lack of established dealer network.	Secondary barrier	Build a network of dealer.
(7) Inadequate policy implementation.	Secondary barrier	Formulate/revise policies to support solar PV.
(8) Difficult access to finance for end users.	Secondary barrier	Subsidize promotion of solar technology.

along with the basic installation for domestic electricity use (bulbs, plugs) during the period 2004–2008 to enable them to meet their basic energy needs.

Barriers to achieve final goal are listed as (Ref. [10])

(i) *Investment barrier*. The main barrier to large scale adoption (in rural areas where it is most appropriate) is the economic factor.
(ii) *Technical barrier*. The performance uncertainty and the low market share of the solar photovoltaic technology and the low ability of local technicians to deal with maintenance problems and after-sales services contribute to reduce the reliability of the solar PV systems.
(iii) *Other barriers*. Limited information of the end users, lack of organization capacity and financial resources are also barriers to the adoption of the solar PV systems in large scales in rural areas.
(iv) Therefore, without strong financial support and owing to the afore-mentioned barriers, the diesel generator system will remain the common option, leading to higher emission.

6.4. Case study of Egypt and Zimbabwe

Although renewable energy technologies have made progress in Egypt, it has been limited to technology development, demonstrations and very little commercialization. Effective market penetration of renewable energy technology has been below expectations [11]. In spite of these barriers, solar PV systems still have opportunities and potentials for contribution to the rural development programs.

Only 20% of Zimbabwean households have access to on-grid electricity. Majority of community could not afford to utilize the electricity due to lack of access to financial and technical resources [11]. Alternative energy sources were recognized as a viable solution for the energy needs of the poor (Table 4).

6.5. Case study of India

In India, 46% of the population, mostly rural community, has no access to electricity. Fueled based lighting, Kerosene lamps, is used for illumination, contributing to global warming and also causing serious health problems. In this context, solar photovoltaic systems offer a good alternative for electrification in rural and remote parts of India [12,13]. However, several issues need to be addressed to improve the acceptability of solar photovoltaic systems by rural population.

(a) Absence of government subsidy programs. Solar photovoltaic system's too expensive and unaffordable.
(b) No Awareness of solar photovoltaic systems and their benefits.
(c) Lack of marketing network in rural parts.
(d) Reliability of solar photovoltaic system.
(e) Non-provision of after-sale service. No service back-up network.

Recently, Solar Electric Company Pvt. Ltd., Bangalore, India, has developed a business model through innovative rural financing schemes for creating a maintenance network in the villages. However, reliability of the system, particularly service after sale and network in case of any technical faults, is debatable. To increase the acceptability and market share of any new technology, the reliability of the systems is the most important and an imperative.

6.6. Case study of Vientiane, Lao PDR

(a) Solar home systems and portable solar lamps are rented at prices starting lower than the spending on kerosene for lighting, so that families can save money by switching to solar PV. Model to enhance the use of solar lamp systems is described below [14].
(b) Uses a carefully selected and trained network of franchises to install and maintain the solar PV equipment, and each franchise trains technicians in the villages to perform day-to-day maintenance.
(c) Rents equipment to the Village Energy Committee (VEC), who are selected by the whole community, and the VEC leases it onto individual households.
(d) Community is responsible for setting prices, collecting rents and performing basic maintenance.
(e) Larger village systems provide power to community services such as health systems and water pumping.
(f) This business model ensures high-quality solar PV lighting and good customer service at a price people can afford.

6.7. USAID project in the Philippines

In Philippines, USAID is developing off-grid renewable energy systems in 160 remote rural communities in the autonomous region in Muslim Mindanao, through the alliance for Mindanao off-grid renewable energy [15].

The program addresses specific barriers to widespread adoption of rural energy technologies. Barriers include

(i) Lack of awareness of the costs and benefits of renewable energy technologies.
(ii) Prevalent policy bias towards fossil fuels.
(iii) Lack of adequate financing and ability to pay, and limited institutional policy.
(iv) Lack of sectoral specialists in understanding how renewable energy technologies can be applied in their sectors, including

Table 4
Case study of Zimbabwe.

Barrier	Causes for barrier	Degree of barrier
Economic and financial	Cost of installation and after-sales services are very high. Estimated to be about 30% of the total costs of PV systems. High capital cost and lack of financing mechanism.	Major barrier – I
Awareness/information	Awareness on the applications of solar photovoltaic systems is very low.	Major barrier – IV
Technical barrier	Lack of access to technology, inadequate maintenance facilities, bad quality product. Lack of skilled manpower and training facilities.	Major barrier – II
Market barrier	Small size market. Limited involvement of private sector.	Major barrier – III
Social barrier	Lack of social acceptance and local participation.	Major barrier – V
Institutional	Unfavorable energy sector policies and unwieldy regulatory mechanisms.	Secondary barrier

health, education, agriculture, and information and communication technologies.

USAID addresses these barriers by overcoming technical, financial, policy and institutional challenges.

Through solar-powered battery charging stations and individual batteries, residents are now saving 70% each month of what they used to spend on kerosene for light. Residents have increased opportunities for productive activities such as mat weaving, sewing, extension of daylight hours for study time and household work.

7. Solution to enhance the acceptability solar-powered LED lighting technology

Solar-powered LED lighting technologies have a niche in rural areas that are off-grid and for the most part have no available electricity. Therefore, focus should be for providing clean energy for certain productive uses across non-energy sectors and not solely for the sake of installing units. The success of the any new technology depends on the viable business model and widespread adoption by consumers. Acceptable business and rural consumer friendly models are desirable to enhance the market share of solar-powered LED technology. Fig. 4 shows the proposed model to enhance the market share of solar-powered LED lighting technology.

7.1. Business model

Finance scheme

- Financing institutions need to be educated about the nature, and future potential of renewable energy technologies – particularly local and regional commercial banks.
- Increased knowledge about these technologies can stimulate investment, lending and business.
- Rural financing scheme through the village body with adequate safeguards for repayments through peer pressures. A loan will be made available from the bank directly to the Village Committee, thus avoiding time and middle persons. However, such loan schemes should ensure that the consumer would be able to buy solar system as per his requirements and choice.

Marketing – subsidy/no subsidy

- With the government subsidy, the solar system up-front cost can be made affordable and end users mostly in rural areas have to pay small amount initially and remaining balance payment may be divided in several installments. Government subsidy scheme may be implemented either through NGOs, private business establishments, village organizations or other government organizations in rural areas.
- With the absence of government subsidy program, private business owners and NGOs may develop an innovative consumer finance scheme through rural credit institutions or through village body with loans from commercial banks. Village organization/body sales solar systems along with installation, maintenance and also ensures repayment of loan.
- However in both financing schemes, the fear is that the end users may be compelled to buy certain substandard outdated solar system units. Consumers must be given an opportunity to buy modern solar system model as per his needs thus ensuring enough scope for future technology innovation.
- Rent solar photovoltaic systems to Village Committee at prices starting lower than spending on kerosene for lighting. Success of the scheme depends on the Village Committee and participation of local communities as Village Committee is responsible for the installation, maintenance, and collection of energy bills.

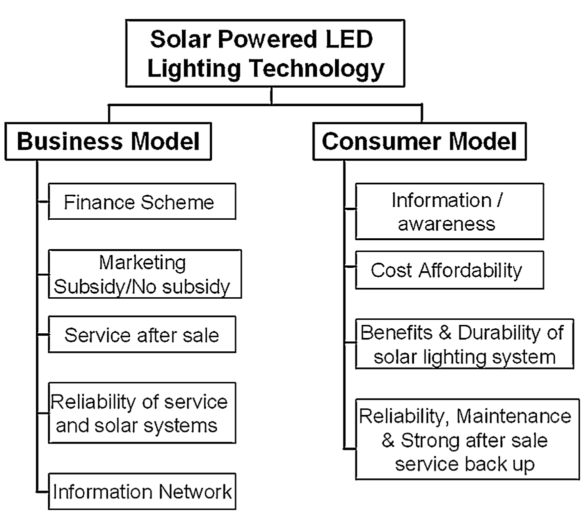

Fig. 4. Model to enhance the use of solar-powered LED lighting technology.

Service after sale

- Trouble free light source with minimum maintenance expenditure.
- Trained local technicians for door-step installation and maintenance.
- Quick after-sale service and regular check up.
- Local infrastructure for repair and maintenance to provide quick and effective services in case of any technical failure of the system.
- Solar battery bank and availability of other components locally.

Reliability of service and solar systems

- Success of the clean light to rural community scheme and solar-powered LED lighting technology depend on the reliability of the system.
- Solar-powered LED lighting technology must give confidence to end users that they will get electricity supply without any failure.
- Efficient service from local technicians is very important. Some incentives (or commission) from the manufacturers/local dealers may motivate technicians to provide the service immediately.

Information network/training network

- Increase understanding of solar PV technology to the large community via TV/radio programs, personal networks.
- Community technology demonstrations. At least one demo-project at public meeting place/religious place/village chief house.
- Dissemination of information about the solar systems through religious/community services.
- Network system which can give information about the minor repair and maintenance of the solar system.
- Network between dealers and local technicians to understand the difficulties faced by the end users.

7.2. Consumer model

Information/awareness

- Raising awareness about the new lighting technology in rural communities.
- Community awareness program to help people to understand how they can help themselves to maintain and use the system.

- Awareness program about the viability and reliability of solar-powered LED lighting technology.

Cost affordability

- If energy hub is used to provide the electricity to entire village, some credit system should be made available to help poor communities who have limited ability to pay.
- Micro-credit system with extremely low interest as up-front cost of solar system is beyond the paying capacity of rural population.
- They may be allowed to make payment even on daily basis. The amount may be of the order of the daily consumption kerosene fuel.

Benefits and durability of solar lighting system:

- Economical compared to kerosene fuel-based lighting and solar-powered CFL lighting. Health benefits, free from fumes and pollutant gases.
- Improved quality of life.
- Increased opportunities for productive activities for income generation to support family by setting-up small-scale business at home.
- Income generation activities in health, education, agriculture and information/communication sectors.
- Significant increase in monthly saving.

Reliability, maintenance and strong after-sale service back up

- Reliability of solar system to provide the uninterrupted electricity is the most important for end users.
- Durability of lighting system.
- Dealers/technicians must ensure end users that they will get electricity through out the day.
- High-quality lighting and good service at a reasonable cost so that people can afford.

Other benefits

- Opportunities to develop new DC driven appliances and other solar-powered driven equipments in health, education, agriculture and information/communication sectors to boost rural economic development.

7.3. Energy hub

Recently, OSRAM's set up an energy hub in April 2008 in Mbita which supplies up to 10 kW of electricity. This is enough to recharge around 350 lamps per day. In addition to the lamps, the energy hub also charges batteries that can be connected to electrical devices such as radios. When the lamps and batteries run out of power, they can be exchanged for recharged devices under the deposit system that has been set up. In this way the equipment can be regularly maintained and controlled, which gives the system a further advantage over other solutions: proper maintenance ensures a long life, and also create new jobs.

8. Conclusions

It is believed that LEDs operated using a solar energy offer a solution to provide the clean and affordable light to 1.6 billion people around the world, mostly in Asia and Africa who are living without electricity and currently use kerosene lanterns as a light source. Replacing kerosene with the LED lights offers an array of benefits: reduced air pollution, improved studying conditions for children, and reduced spending by poor families on kerosene. Quality of Life is improved. Use of solar-powered white LEDs significantly reduces power consumption, no environment contamination by mercury, and increases monthly savings by up to 70%. The greenhouse gases associated with the kerosene based lighting will be completely minimized with solar-powered white LED lighting systems in developing countries.

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